DØ Note #3755

The DØ Run 2b Upgrade: Status and Plans

The DØ Collaboration

June 5, 2000

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1. Introduction

In the early 1980's, the DØ collaboration embarked on a broad and exciting program to study physics at the energy frontier with a powerful new detector. Our efforts in building the DØ detector were amply rewarded by the rich physics that emerged from Run 1, highlighted by the discovery of the top quark. After another long period of detector construction, we are nearing completion of the DØ upgrade and will soon be taking data with a significantly improved detector designed to exploit the opportunities provided by the upgraded Tevatron.

Our physics goals for Run 2 are ambitious; a partial list includes:

- Discovery of the Higgs boson,
- Finding new physics beyond the Standard Model (SM), such as supersymmetry,
- Making detailed measurements of top quark properties,
- Precisely measuring the top quark and W boson masses,
- Measuring CP violation in B decays, and
- Performing QCD studies at high and low Q^2.

The degree to which the above physics program is successful depends critically on two factors: the integrated luminosity delivered to DØ and the performance of the DØ detector.

We believe that the clearest case for maximizing the integrated luminosity is found in the search for the Higgs boson. The SM Higgs boson mass is currently constrained to be greater than 107.7 GeV by direct searches at LEP[1] and less than 188 GeV by electroweak radiative corrections[2] (both limits are at the 95% confidence level). Figure 1 shows the discovery reach for a SM Higgs boson expected in Run 2.[3] With the ~2 fb^{-1} luminosity goal for Run 2a, there is little sensitivity for the SM Higgs beyond the range already covered at LEP. However, the situation changes dramatically with a further factor of 10 increase in integrated luminosity. For example, with an integrated luminosity of 20 fb^{-1} per experiment, we expect to be able to:

- Make a 5+ s.d. discovery for m_H < 120 GeV,
- See a 3+ s.d. signal for m_H < 180 GeV, or
- Exclude the Standard Model at the 95% CL if there is no sign of the Higgs.

Our best hope for fully exploiting the tremendous physics opportunities offered by the Tevatron collider is to maximize the integrated luminosity delivered to the collider experiments, with a Run 2b goal of at least 15-20 fb^{-1} per experiment.

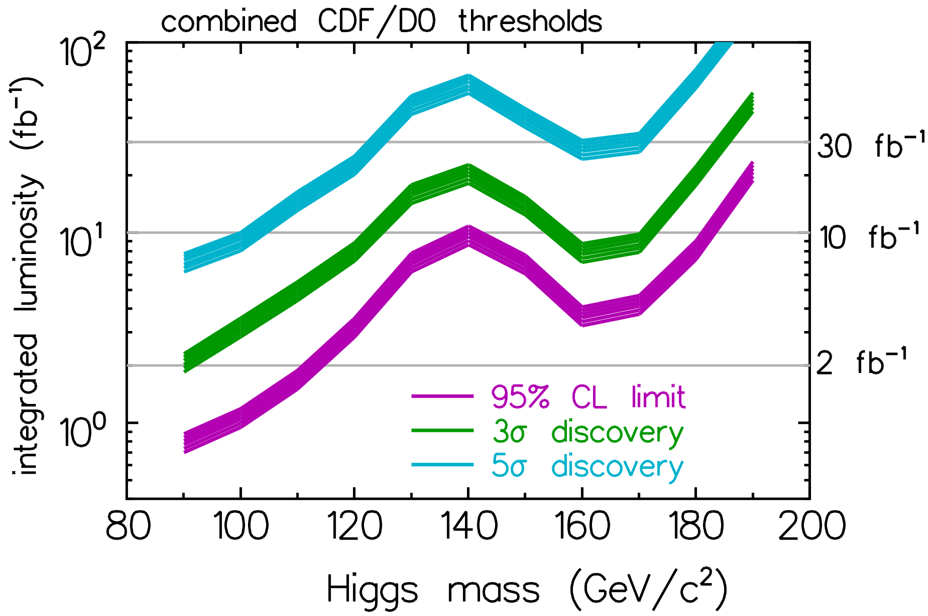

Figure 1: SM Higgs discovery reach at the Tevatron. The lower edge of the bands shows the expected luminosity threshold; the upper edge shows the effect of increasing the expected luminosity threshold by 30%.

The other critical factor in meeting our Run 2b physics goals is the performance of the DØ detector. The current DØ upgrade design is based on the 2 fb^{-1} luminosity goal for Run 2a. To achieve an integrated luminosity of 15-20 fb^{-1} for Run 2b, the Tevatron will have to run at peak luminosities of ~5×10^{32} $cm^{-2}s^{-1}$ for a period of 3-4 years. This luminosity is a factor of 2.5 greater than the design goal for Run 2a, substantially increasing the occupancy in tracking devices and leading to radiation damage in some detectors. These concerns have led us to begin developing plans for a Run 2b upgrade to maintain the capabilities of the DØ detector.

To better understand the impact of extended running at high luminosity, DØ held a one-day workshop in March 2000 to evaluate the anticipated performance of the DØ detector systems in Run 2b.[4] What emerged was an outline of the required upgrades:

- Replacement of the inner layers of the silicon vertex detector due to radiation damage,
- Construction of an additional silicon layer to improve b-tagging efficiency and tracking pattern recognition,
- Improvements to the trigger system to handle the higher physics rates and detector occupancies,
- Possible need to replace the parts of the fiber readout electronics due to problems operating at 132 ns bunch spacing, and
- Possible need for improvements in the muon system to deal with wire aging and high occupancies in the central muon drift tubes.

Initial plans for these Run 2b upgrades were presented at the April PAC meeting. We appreciate the PAC's encouragement, and have continued to develop our Run 2b upgrade design and R&D plans. We are currently exploring various options for each element of the upgrade, with the goal of converging on the most promising options during the June DØ collaboration workshop. We are also working to identify the R&D needed for the Run 2b upgrades, especially for those items with long lead-times. We anticipate developing a detailed R&D plan in the coming months.

In the next section, we briefly describe the Run 2b upgrade options being most vigorously pursued at this time. Our current understanding of the required R&D is described in Section 3, followed by concluding remarks in Section 4.

2. Run 2b Upgrade Options

DØ is investigating a variety of Run 2b upgrade options to help us identify those options that will best meet our physics goals and schedule constraints. In the sections below, we describe the options under consideration for maintaining the performance of the silicon tracker, providing an additional silicon layer, developing new silicon readout chips, and improving the trigger. We also discuss our concerns about the fiber readout electronics and the central muon chambers.

Silicon Tracker Options

This section describes the options under consideration for maintaining the performance of the Run 2a silicon tracker throughout Run 2b. We begin by describing the problem of radiation damage to the inner silicon layers, followed by discussion of the partial replacement and full replacement options for the silicon barrel detectors. We also describe the options under consideration for the forward tracker.

<u>Radiation Damage in the Silicon Detector</u>

We expect that the present DØ SMT silicon sensors will be able to withstand a radiation dose of ~2 MRad.[5] Charged particles from beam-beam collisions are the dominant source of radiation damage; the expected radiation dose per fb^{-1}, $\Phi(r) = 2.22/r^{1.68}$ MRad/fb^{-1}, was empirically derived from CDF SVX data[6] and is shown in Figure 2. Layer 1 (L1) accumulates 0.4 MRad/fb^{-1} and will need to be replaced after ~5 fb^{-1} of integrated luminosity; Layer 2 will need replacement after ~11 fb^{-1}. Thus, at least two silicon layers must be replaced to maintain the functionality of the silicon detector in Run 2b.

Due to the low manufacturing yield and insufficient radiation hardness of the double-sided silicon sensors in the current upgrade, we plan to use two rad-hard single-sided sensors that are glued back-to-back as a substitute for double-sided sensors. This will allow us to use a more reliable technology, while continuing to make both axial and stereo measurements. The only drawback of this approach is the increased thickness of the silicon sensors, an issue we discuss in the next section. We are currently considering two rad-hard sensor technologies: low-resistivity silicon[7] and oxygenated silicon.[8]

Since Layers 3-4 are expected to survive at least 20 fb^{-1} of integrated luminosity, we have a choice of replacing only Layers 1-2, or making a complete replacement of Layers 1-4. There are advantages to both approaches, and we are presently investigating both options. We provide here a summary of our current understanding of these options.

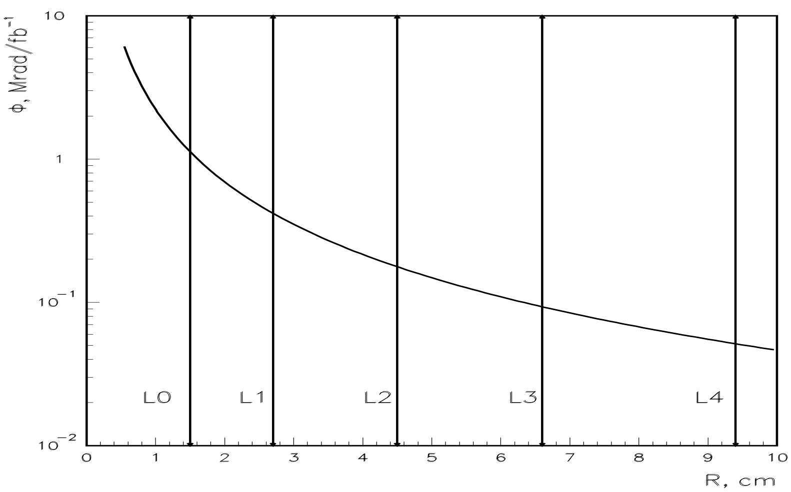

Figure 2: The radiation dose per fb^{-1} received by silicon sensors as a function of their radial position. Vertical lines show the positions of the silicon sensors for Layers 1-4 in the present DØ tracker and for a possible new inner Layer 0.

Partial Replacement Option

If only Layers 1-2 are replaced, we save the expense and manpower required to build new support bulkheads and the ladders for Layers 3-4 (2/3 of all the ladders in the current design). A preliminary plan for replacing these layers, based on our experience building the current silicon tracker, is described below.

A concern with the partial replacement option is whether Layers 3-4 are sufficiently rad-hard. To minimize reverse annealing effects, we would remove the silicon tracker from DØ and keep it in cold storage when it is not being worked on. A calculation of the expected depletion voltage for Layer 3 shows that it remains under 100 volts for 20 fb^{-1} of integrated luminosity, including a 12 week warm period after 3.5 fb^{-1} for Layer 1-2 replacement.[9] Thus, our best information at this time indicates that Layer 3 can tolerate several weeks at room temperature after Run 2a and still survive the radiation dose expected during Run 2b.

The ladder replacement would begin by warming one of the barrels to bring it closer to room temperature. The High Density Interconnect (HDI) tails that bring out the electrical signals for Layers 1-2 would be cut and extracted from the barrel. The Layer 1 ladders and the inner 6 ladders for Layer 2 would be quickly removed, as their removal does not endanger ladders in Layers 3-4. The outer 6 ladders in Layer 2 would be removed by reversing the installation procedure. Figure 3 shows the installation of the final ladder in the first DØ barrel detector, including the mounting fixture used to hold the ladder during installation. After the ladder is in place, pins are installed to hold the ladder in position. We anticipate that removing the old ladders will take 2 days. Our experience is that new ladders can be installed at a pace of about 6 a day. An additional day will be needed for surveying the barrel, leading to an estimate of ~7 days per barrel to replace Layers 1-2. Completed barrels would be installed in the support cylinder and aligned in a manner similar to that used for the Run 2a detector. A realistic estimate of the time required for replacing Layers 1-2 will be possible after the Run 2a detector is installed; at present, the partial replacement option appears to be feasible during a shutdown of modest duration.

A potential concern with the partial replacement option is whether we can keep the inner-layer sensors sufficiently cool during Run 2b to minimize the increase in depletion voltage from reverse annealing. The existing bulkheads provide cooling for the readout chips, and rely on thermal conduction to cool the sensors. Further studies are needed to determine if the present cooling system is adequate.

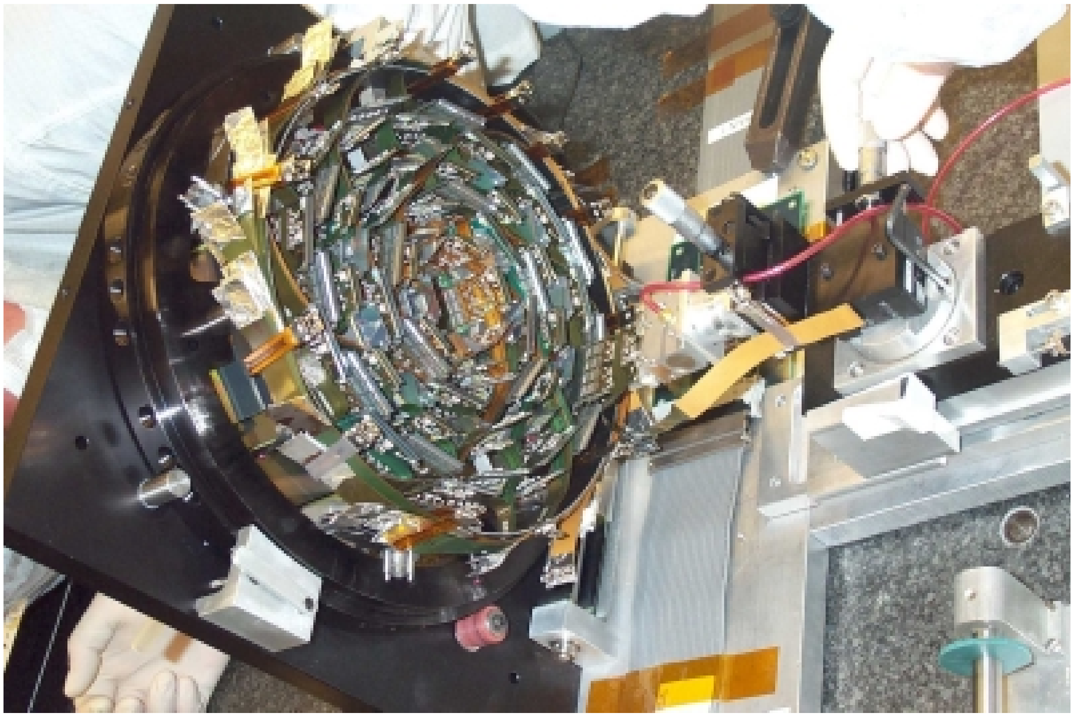

Figure 3: Installation of the final ladder in the first DØ barrel detector. The moving fixture is shown on the right holding a ladder as it is being installed into the detector.

Full Replacement Option

We have also initiated a study of the full replacement option where we would build entirely new barrel detectors. Advantages of replacing the entire silicon tracker include minimizing the length of the shutdown, avoiding the need to replace the delicate silicon ladders on a tight schedule, elimination of concerns about the radiation hardness of Layers 3-4, and increased flexibility in designing the Run 2b upgrade. While there is a possibility that the partial replacement option could be done using leftover SVX 2e readout chips, the full replacement option will most definitely require a new readout chip design. We have just begun to look into the full replacement option, and hope to have a clearer understanding of the relative merits of the two options in the near future.

Forward Tracking Options

In addition to the silicon barrel detectors, DØ is building silicon disk detectors to provide forward tracking coverage and extend the effective length of the silicon tracker to accommodate the large size of the luminous region (σ_z~25 cm) during the start of Run 2a. While we expect the Tevatron to operate with a crossing angle during Run 2b, reducing the size of the luminous region to σ_z~12 cm, it remains desirable to maintain forward tracking out to at least $|\eta|<2$ to match the coverage of the muon detector. One option would be to leave the F-disks and H-disks in their current locations. The F-disks will be exposed to non-uniform irradiation, so part of the detector at low radius will not be fully depleted, adversely affecting the signal/noise ratio. The minimum radius of the H-disks is 9.5 cm, and we do not expect they will experience significant radiation damage. A second option would be to build two additional barrel detectors, giving a total of 8, with the new barrels having only Layers 3-4 instrumented. Spare bulkheads are available, so it may only be necessary to manufacture additional silicon ladders. This option provides good tracking coverage out to $|\eta|=2$, and would allow some or all of the disk detectors to be removed. We are not considering building new F-disks at this time.

Additional Silicon Layer

Many of the Run 2 physics goals, including Higgs discovery and top quark studies, are heavily dependent on tagging b-quarks. Both the partial replacement and full replacement options utilize silicon ladders made from two single-sided sensors glued together. The increased multiple scattering from the double thickness of silicon will degrade the impact parameter resolution and reduce the b-tagging efficiency relative to Run 2a. The present resolution can be recovered – in fact, can be substantially improved – by adding an additional silicon layer. The improved impact parameter resolution would increase the b-tagging efficiency and allows us to make the best use of the delivered luminosity. An additional silicon layer would also help track reconstruction in the high-occupancy environment anticipated for Run 2b.

We are considering three options for the additional silicon layer: an inner layer of strips, an inner layer of pixels, and an outer layer of strips. A brief summary of each option follows.

Layer 0 Strips

The Layer 0 strip option adds an additional layer of silicon strips inside Layer 1. The impact parameter resolution is improved significantly by making a precise measurement of the track in the r-ϕ plane at the smallest possible radius. The minimum radius for the Layer 0 strips is limited by radiation damage, with an exposure of ~1 MRad/fb^{-1} at a radius of 1.5 cm (see Figure 2). This radius is also safe from beam halo, both at injection time and during data taking, because the detector is always in the "shadow" of the low-beta quadrupole magnet. We describe here an initial design for the Layer 0 strip option.

Twelve Layer 0 ladders are arranged in a barrel to preserve the 6-fold axial symmetry of the present silicon tracker, as shown in Figure 4. The overlapping ladders provide redundant coverage and minimize dead regions. As in the present tracker design, there are 6 such barrels along the beam direction.

Each ladder contains a single 12 cm long silicon sensor with 25 μm pitch axial strips and four readout chips, two at each end. Since the readout chip pitch is typically 50 μm, neighboring strips are read out on opposite ends of a ladder. All Layer 0 sensors are identical and thus only 1 detector mask is needed. Because of concerns about radiation damage, the readout chips might be moved to a larger radius (~3 cm) and connected to the sensors by fine-pitch flex circuits.

As is the case with all of the options for an additional silicon layer, there are many detector and engineering issues that must be resolved. R&D support is urgently needed to understand issues of radiation damage, mechanical support, cooling, cabling, ladder design, and changes to the beam pipe.

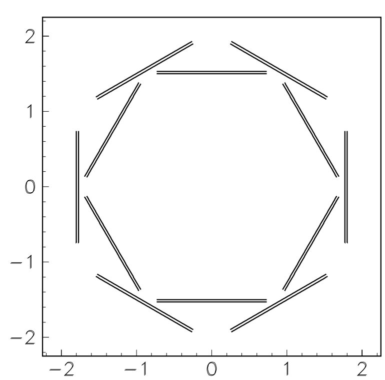

Figure 4: Sketch of the geometry in the r-ϕ plane for the Layer 0 strip option.

Layer 0 Pixels

A second option for a silicon Layer 0 is to use pixel detectors located close to the beam pipe. Pixel detectors have distinct advantages in being very radiation hard and providing full 3-D space points. The very large number of channels and low occupancy per channel are unique features of the pixel option that would undoubtedly be helpful in track finding. We are also exploring the possibility that pixels could be incorporated into the Level 1 tracking trigger to improve trigger rejection and provide an impact parameter trigger at Level 1.

We have had discussions with the Fermilab Rad-Hard Vertex Detector group to better understand the status of the pixel development efforts at Fermilab and how this work might be used by DØ in Run 2b. We have been impressed by the work of this group, but must develop a better understanding of the advantages and disadvantages of the Layer 0 pixel option. Concerns include increased multiple scattering relative to strip detectors, integrating the FPIX readout chip into the DAQ system, and the potential schedule risk associated with this new technology.

Layer 5 Strips

We are also considering an "ISL" option where we would replace the inner two layers of the fiber tracker with silicon strip detectors to add a Layer 5 to the silicon tracker. At a luminosity of 5×10^{32} $cm^{-2}s^{-1}$ with 103 bunches, the occupancy in the inner fiber layers is expected to be ~20%, reducing the effectiveness of these layers for triggering and tracking. With ~150 μm pitch silicon sensors, the occupancy would be reduced significantly, improving pattern recognition in the tracker. The Layer 5 ladders would be generally similar to the Layer 1-4 ladders. Axial and stereo measurements would be achieved by gluing two single-sided detectors back-to-back, while readout would be done using SVX 2 chips (or their replacement).

With the additional stereo measurement in Layer 5, we have the option of building Layer 1 with only axial strips (to minimize multiple scattering) if studies show that this improves b-tagging efficiency. It may also be possible to improve the impact parameter resolution by increasing the precision of the Layer 1-2 measurements, either by decreasing the strip pitch or employing an intermediate strip in the Layer 1-2 sensors.

Since this option eliminates two of the fiber layers, the tracking trigger would require modification. One possibility would be to include the stereo layers in the trigger, and is discussed below.

Silicon Readout Options

We are presently using the custom designed SVX 2e chip[10] for reading out the silicon tracker and fiber detectors. This chip was fabricated using UTMC's rad-hard 1.2 micron technology. We estimate that with the completion of the Run 2a detectors and our present yield of 60%, we will have approximately 2500 chips that could be used for the Run 2b upgrade. These chips appear to be able to survive a radiation dose of ~6 MRad.

The number of new chips needed for Run 2b depends on the scope of the upgrade. For replacement of silicon Layers 1-2, we would need 1008 good chips, not including spares. The Layer 0 strip option would require an additional 288 chips, the Layer 5 strip option would require 700-1400 chips depending on the strip pitch, and the forward barrel option would require 720 chips. Rebuilding the fiber readout MCMs or choosing the full replacement option would require an additional source of readout chips.

If the existing supply of SVX 2e chips is inadequate, we cannot simply purchase additional chips since the UTMC 1.2 micron rad-hard technology is no longer available. Options that have been explored include:

- Procuring rad-soft SVX 2 chips for the fiber readout electronics,
- Obtaining SVX 3 chips from Honeywell,
- Redesigning the SVX 2 chip in 0.8 micron SOI technology,
- Redesigning the SVX 2/3 chip in 0.25 micron technology, and
- Using the CMS APV 25 chip.

A joint effort with CDF to redesign the SVX 3 chip in 0.25 micron technology would have advantages for both collaborations and is the option we have looked at most closely. Indications are that the tools available for chip design with the 0.25 micron technology are more advanced and accurate than for previous technologies. The radiation hardness comes without special processing and is probably better than either the SVX 2 or SVX 3 chips. While the development time for a new readout chip is a concern, the turn-around time should be considerably faster than for the previous rad-hard submissions since we would be using an industry standard process.

Trigger Improvements

A robust and versatile trigger is an essential part of a hadron collider experiment. While the existing trigger framework is sound, we anticipate needing to make incremental improvements to several trigger systems for Run 2b. The higher luminosity for Run 2b will require us to be more selective in our triggers to keep trigger rates at an acceptable level. Not only do the rates for physics processes scale with luminosity, but at high luminosity the large number of proton-antiproton interactions in a typical beam crossing leads to a drop in the trigger rejection power. We estimate that a factor of 2-4 improvement will be needed in the product of Trigger Rejection $\times$ Trigger Rate at each level of the trigger.

Further study is needed to identify the optimal mix of trigger upgrades. We describe here two options, a Level 1 tracking trigger upgrade and a Level 1 calorimeter trigger upgrade, which have been presented at DØ Run 2b meetings. In addition, we would likely upgrade the processing power of the Level 2 and Level 3 triggers, as more powerful CPU's become commercially available, and increase the Level 3 trigger rate to write more events on tape.

At high luminosities, multiple interactions cause a substantial increase in fiber tracker occupancies, leading to an increase in the number of "fake" tracks from random combinations of hits. This will be especially true if we decide to remove the inner fiber layers to provide room for a 5^{th} layer of silicon strips. One option that we have begun to investigate is to include the stereo fiber layers in the track trigger to reduce the probability of fake tracks. Since the readout boards for axial and stereo fiber layers share a common design, the stereo hits are readily available. New stereo-layer track trigger logic would have to be developed to find tracks in the stereo layers and match them with the tracks in the axial layers.

The DØ Level 1 jet triggers are based on the transverse energy in 0.2×0.2 trigger towers exceeding programmable thresholds. Since jets typically spread their energy over many trigger towers, the jet triggers have an extremely slow turn-on curve. One option for sharpening the jet energy threshold is to base the trigger on overlapping 3×3 or 4×4 groups of trigger towers. The tower energies are not easily accessible in the current Level 1 trigger design, but the bits indicating which energy thresholds were exceeded for each trigger tower are accessible. By combining the threshold bits from several neighboring trigger towers, it should be possible to make a better estimate of the jet energy than is possible using the bits from a single tower. Given the steeply falling jet energy spectrum, even a modest improvement in the trigger turn-on curve could be useful. The same technique could be used to improve the turn-on of the electron trigger and possibly impose electron isolation and track matching criteria at Level 1.

Fiber Readout Electronics

We are having difficulties making the fiber readout electronics operate with a bunch spacing of 132 ns. The problem is associated with the "SIFT" chip, a custom chip that discriminates the VLPC signals and provides a pick-off that allows an SVX 2e readout chip to measure the amplitude of the signal. The SIFT and SVX chips are mounted on Multi Chip Modules (MCMs), which are then mounted on Analog Front-End (AFE) boards. Thus, if we decide to replace the SIFT chip, we would also need a substantial number of SVX chips (or their replacement) for the fiber readout electronics.

At this point, we lack definitive information on whether it will be necessary to replace the MCMs and/or the AFEs for 132 ns operation. While our efforts are currently focused on bringing the fiber tracker readout electronics into operation with 396 ns bunch spacing, we will continue to study this problem so that we can better understand what options are available to us.

Central Muon System

We have some concerns about the performance of the B/C layer central muon drift tubes. These drift tubes are unchanged from Run 1, where significant aging was observed in areas with high background rates. Backgrounds also increase the chamber occupancy, which can generate fake tracks in the muon system. These backgrounds are largely due to beam halo and particles that escape through gaps in the calorimeter and far exceed the rates for real muons. For Run 2, we have added a significant amount of new shielding in an effort to keep these particles out of the muon system.

Replacing the central muon drift tubes would be a major undertaking, and is not an option we are considering for Run 2b. During Run 1, we found that we could clean the wires by “zapping” them with a large current discharge. We expect that it will be necessary to occasionally clean the wires in this manner during Run 2. Our best estimate is that wire cleaning will need to be performed roughly once per fb^{-1}, but the actual level of backgrounds and their distribution across the detector won’t be known with certainty until we start running. If we find that backgrounds in the B/C layer muon drift tubes are at a level that would adversely affect the Run 2b physics program, we would likely want to implement modest upgrades to the central muon system that would help mitigate the problem.

3. Preliminary Plans for FY2001 R&D Program

We have presented a number of options for Run 2b upgrades that are under consideration by the DØ collaboration. We believe this is a sign of the vigor and interest by the DØ collaboration in Run 2b, as well as the youth of the Run 2b effort. We hope to begin the process of narrowing our options at the June DØ workshop, and continue working towards a more detailed blueprint for the Run 2b upgrade over the course of the summer. As we narrow our options, the required R&D will become better defined, allowing us to prepare a more detailed R&D plan.

The broad outline of the R&D program required for Run 2b is beginning to emerge. We describe below the critical, long-lead time R&D that must begin as soon as possible to meet the tight schedule for the Run 2b upgrade.

<u>Development of a new readout chip for the silicon tracker</u>

If our present supply of SVX 2e readout chips is inadequate for the Run 2b upgrade, we will need a new readout chip. Since CDF is very likely to require a new readout chip, there are clear advantages to a joint CDF/DØ effort, provided the needs of the two experiments can be accommodated in a single chip design. Given the long lead-time for chip development, this effort should begin as soon as possible.

<u>Silicon radiation damage studies</u>

We need to improve our understanding of the effect of radiation on the silicon detectors being built for Run 2a and under consideration for Run 2b. While we expect Layers 3-4 to survive the radiation dose in Run 2b, the inner layers see very high doses and we need to make realistic radiation damage tests of the low-resistivity silicon and oxygenated silicon sensor technologies. We also need to perform further radiation testing of the barrel and disk detectors being built for Run 2a to better understand how their performance deteriorates as a function of radiation dose and the effect of non-uniform irradiation on the F-disks.

<u>Fabrication and testing of prototype silicon detectors</u>

Construction and testing of prototype silicon detectors, including sensors and readout chips, is a critical step in preparing for the construction of new silicon ladders. Among the options to be studied are 25 μm pitch sensors with readout on both ends, 25 μm pitch sensors with readout on every other strip, and 150 μm pitch sensors. We can use SVX 2e readout chips for initial tests, even if we eventually use a different readout chip. These studies will help establish the back-to-back fabrication procedure and characterize the performance of these detectors.

Mechanical engineering for the silicon detector upgrades

A wide variety of mechanical engineering studies are needed for the silicon detector upgrades. One of the most important issues is the procedure for replacing the silicon detector. We may be able to install the Run 2b upgrade in a relatively short shutdown if we can perform the upgrade in the collision hall. We note that the "split cylinder" design was adopted for the Run 2a silicon detector to allow installation (and thus replacement) in the collision hall. Addition of a Layer 0 silicon detector may require the installation of a new beam pipe; if so, we need to understand the installation procedure, the required configuration of the DØ detector, and the impact on the length of the shutdown. Another important issue is cooling the inner layers to minimize radiation damage. We need to understand whether there is sufficient cooling for Layers 1-4 in the partial replacement option, and how to cool the sensors and readout electronics for the Layer 0 designs. Additional mechanical engineering is needed for a variety of tasks, including ladder design, mechanical supports, and cabling for the additional silicon layer.

Electrical engineering for silicon upgrades, trigger upgrades, and fiber readout electronics

Every area of the Run 2b upgrade has needs for electrical engineering support. The silicon upgrades require new flex circuit designs. If we adopt a new SVX readout chip, we will likely need new interface boards to adapt the SVX signals to the DAQ system. The design of new trigger electronics comprises a large part of the trigger upgrades. Finally, if we are not able to resolve the fiber readout problems, substantial engineering will be needed to design new MCM and/or AFE boards.

Simulation studies

In addition to the hardware R&D projects described above, simulation studies are needed to guide our choice of upgrade options and optimize the detailed detector design. Examples include studies of b-tagging efficiencies and pattern recognition capabilities for the three additional silicon layer options, studies of the tracking acceptance and resolution for the forward tracking options, and studies of trigger rejection improvements that can be obtained with the tracking trigger and calorimeter trigger upgrade options.

4. Conclusions

DØ's approach to the Run 2b upgrade is to identify the minimal upgrade that will allow us to fully exploit the rich physics opportunities at our doorstep. The best chance of meeting our luminosity goals before the start of LHC physics is to install the Run 2b upgrades in late 2003 or early 2004, so that high luminosity running can begin in 2004. Given the aggressive time scale, it is critical that a serious R&D program be initiated in FY2001, followed by detector construction in FY2002-3.

5. References

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